First, some quick logisitics on your final project

Please keep the video < 10 min, and **5 min max is desirable!**

The **writeup need not be long** (3 pages is minimum, as in assignment).

Please try to spend more time on a **storyline**, and uncertainty discussion than on formatting, especially for your draft.

Working on **video & text simultaneously** should help **clarify** your story.

Prediction: Week 11

SPACE!

From Fear to Landings: Comets

"Stardust"

Dynamics

The 3-body problem

n-body simulation

Illustris (+more physics)

Astronomy Simulation with **SPACE FUTURES** *experts from the CfA: Breakouts*

Avi Loeb

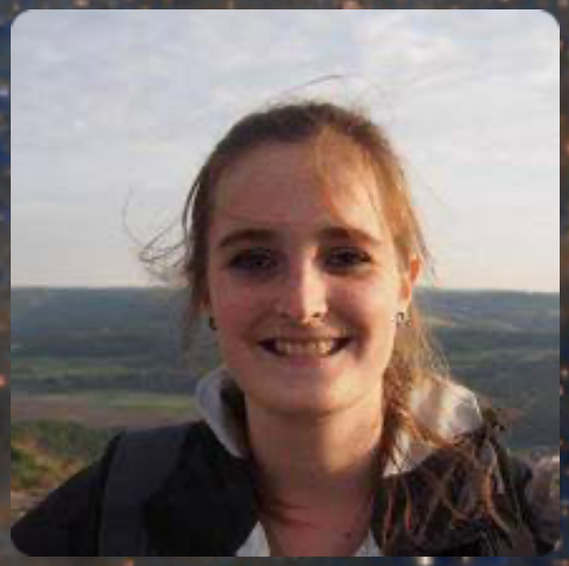
Jill Tarter

Predictions with the Drake equation (groups)

CONTACT(?)

SPACE FUTURES

Making Stars & Galaxies



Dr. Sarah Jeffreson

Dr. Catherine Zucker

Dr. Vadim Semenov

Mike Foley

Gus Beane

The Path to Newton

PREVAILING BELIEF

CONCERNED WITH PHENOMENA

EARTH AT CENTER (⊙ BELIEVED SUN AT CENTER)

TOOLS AVAILABLE

GNOMON

GNOMON

ASTRO

MATH AVAILABLE

ARITHMETIC & ACCOUNTING
ZERO AS PLACE HOLDER
PLANAR GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY

SPRERICAL TRIGONOMETRY

BIG IDEAS

Correct

Partial credit

Wrong

CONNECTIONS BETWEEN IDEAS

Teacher-Pupil or Senior-Junior Researcher

Travel between cultures

Published works

Hey, the cycles in the sky repeat. Let's track them.

BABYLONIANS
c. 2000–300 BCE

Astronomical Diaries

Some "stars" move more than others

Natural, not supernatural.

THALES
624–546 BCE
Greek

Nature can be explained

Motion needs a little push.

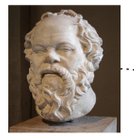
ANAXAGOROS
510–428 BCE
Greek

Motion must have a cause

Motion and change are illusions

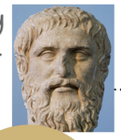
Question all you "see."

PARMENIDES
515–450 BCE
Greek



SOCRATES
470–399 BCE
Greek

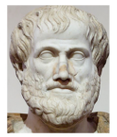
PLATO
427–347 BCE
Greek



Symmetry rules.

The air moves objects through it

Rearranging "atoms" allows motion



Circles spheres, beauty, eternity...

ARISTOTLE
383–322 BCE
Greek

...oh, and you're so wrong about motion, Plato.

All things move to their natural place

Earth is stationary center of the universe

Planets, Moon, Sun, move on spheres

It's spheres all the way down.

EUDOXUS
390-337 BCE
Greek

STUFF on Earth and in the Heavens is all the same... just atoms.

DEMOCRITUS
460–370 BCE
Greek

The universe is WAY bigger than you might think.

ANAXIMANDER
610–546 BCE
Greek

Earth generated by boundless eternity

Universe is spherical

If circles are perfect, spheres are sublime.

PYTHAGORAS
570–495 BCE
Greek

I can prove it!

EUCLID
300? BCE
Greek

A single framework for all geometry

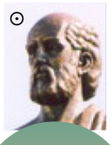
Elements
Euclid
c. 300 BCE

Circles ARE the best! We just need more!

PTOLEMY
100–170
Greek living in Roman Egypt

Epicycles, equants, eccentrics

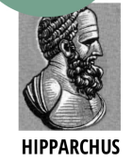
The Almagest
Ptolemy
c. 150



Hello? Is this thing on?

ARISTARCHUS
310–230 BCE
Greek

Sun at center



I'm not sure Earth is exactly in the center?

HIPPARCHUS
190-120 BCE
Greek living in Rome

Math can model the universe

With one little function, I'll give you the Moon!

On the Heavens
Aristotle
c. 350 BCE

Physics
Aristotle
c. 320 BCE

SUN AT CENT

GNOMON
ASTROLABE

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY
SPHERICAL TRIGONOMETRY
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ZERO AS NUMERAL

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ALGEBRA
TUSI COUPLE AND OTHER SPECIAL FORMS

Motion caused by self-exhausting force

Celestial and terrestrial phenomena similar

Aristotle is wrong about space, time, and matter.

JOHN PHILOPONUS
490–570
Greek living in Roman Egypt

Circles ARE the best! We just need more!

PTOLEMY
100–170
Greek living in Roman Egypt

I must gather more information for better astrology, and I shall share what I learn!

VĀRĀHAMIHIRA
505–587
Indian

Epicycles, equants, eccentrics

With one little function, I'll give you the Moon!

ARYABHATA
476–550
Indian

Sines improve accuracy

I'm not sure Earth is exactly in the center?

PARCHUS
-120 BCE
ek living
Rome

Who knew nothing could be so useful?

BRAHMAGUPTA
598–668
Indian

Zero is a numeral unto itself

Accuracy is key (e.g., 365.24 days in a year)

Years from now, Copernicus will love me.

AL-BATTANI
858–929
Arab

It just keeps going, and going... but not really.

IBN SINA (AVICENNA)
980–1037
Persian

Motion is indefinite without external forces

Metaphysics? Hooey! Give me evidence and math.

IBN AL-HAYTHAM
965–1040
Arab

Models matching data is paramount

If I use a teeny unit of time...

BHĀSKARA II
1114–1185
Indian

Much of what we today call calculus

What did Aristotle really mean? We need to question.

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Motion is a chain of an object's locations

Bigger observatories, better observations.

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Motion explained with "impetus theory"

Simple circular orbits work with better math

This is math, not philosophy.

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French

The Earth might actually rotate

Earth need not be at rest, Ptolemy!

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Come on! You can't "give" an object motion.

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The Almagest
Ptolemy
c. 150

Aryabhatiya
Aryabhata
c. 499

On Aristotle's Physics 3
Philoponus
c. 520

Pañca-siddhāntikā
Vārāhamihira
c. 575

Brahmasphuta-siddhanta
Brahmagupta
c. 628

TRANSLATION MOVEMENT WORKS

Kitāb az-Zīj
al-Battani
c. 900

Kitāb al-Shifa'
Ibn Sīnā
c. 1020

Al-Shukūk 'alā Batlamyūs
Ibn al-Haytham
c. 1025

Siddhānta Shiromani
Bhāskara II
c. 1150

Commentaries on Aristotle
Ibn Rushd
c. 1150-1200

Alfonsine Tables
1252

Al-Tadhkirah fi'ilm al-hay'ah
al-Tusi
1261

Epitome of the Almagest
Regiomontanus
1496

De Revolutionibus
Copernicus
1543

Comets in Ancient Times

(with Owen Gingerich & Sara Schechner)

Scrovegni Chapel,
Padua, Italy

Comets in the Middle Ages

Adoration of the Magi

Scrovegni Chapel,
Padua, Italy

Note the comet overhead in this Giotto fresco, painted in the early 1300s. The inspiration for the comet? Halley's Comet, which was visible from Earth in 1301-1302.

SUN AT CENT

GNOMON
ASTROLABE

ARITHMETIC
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PREDICTIONX

SUN AT CENTER (⊕ BELIEVED EARTH AT CENTER)

GNOMON
ASTROLABE
PRINTING PRESS

ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
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SPRERICAL TRIGONOMETRY
ALGEBRA
TUSI COUPLE AND OTHER SPECIAL FORMS

GNOMON
ASTROLABE
PRINTING PRESS
TELESCOPE

ARITHMETIC
ZERO AS NUMERAL RAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPERHICAL TRIGONOMETRY
ALGEBRA
SPECIAL FORMS
LOGARITHMS

ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHRERICAL TRIGONOMETRY
ALGEBRA
SPECIAL FORMS
LOGARITHMS
CALCULUS

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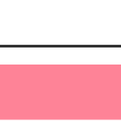

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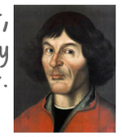

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NICOLE ORESME
1320–1382
French

Planets orbit the Sun, but Sun orbits Earth

TYCHO BRAHE
1546–1601
Danish

With giant spendy instruments, I can get GREAT data.

Jupiter has moons, which orbit like our Moon

JOHANNES KEPLER
1571–1630
German

I have Tycho's fancy data!

Hmm... circles are a problem.

Orbits are ellipses, not circles

Sun is the center

All bodies on Earth have (circular) inertia

All bodies have inertia

GALILEO GALILEI
1564–1642
Italian

Oooh, I like this Dutch spyglass!

Sorry, Aristotle, you're just wrong.

RENÉ DESCARTES
1596–1650
French

Aristotle, mon ami, above and below, it's all matter in motion.

GRAVITY GOVERNS ALL

ISAAC NEWTON
1642–1726
British

We're gonna need better math.

This apple. That moon. Could they feel the same pull?

EDMOND HALLEY
1656–1742
British

I must make Newton publish!

Some comets return, predictably

Commentaries on Aristotle
Ibn Rushd
c. 1150-1200

Alfonsine Tables
1252

Al-Tadhkirah fi'ilm al-hay'ah
al-Tusi
1261

Epitome of the Almagest
Regiomontanus
1496

De Revolutionibus
Copernicus
1543

Astronomia Nova
Johannes Kepler
1609

Siderius Nuncius
Galileo
1610

Dialogue on the Two Chief Systems of the World
Galileo
1632

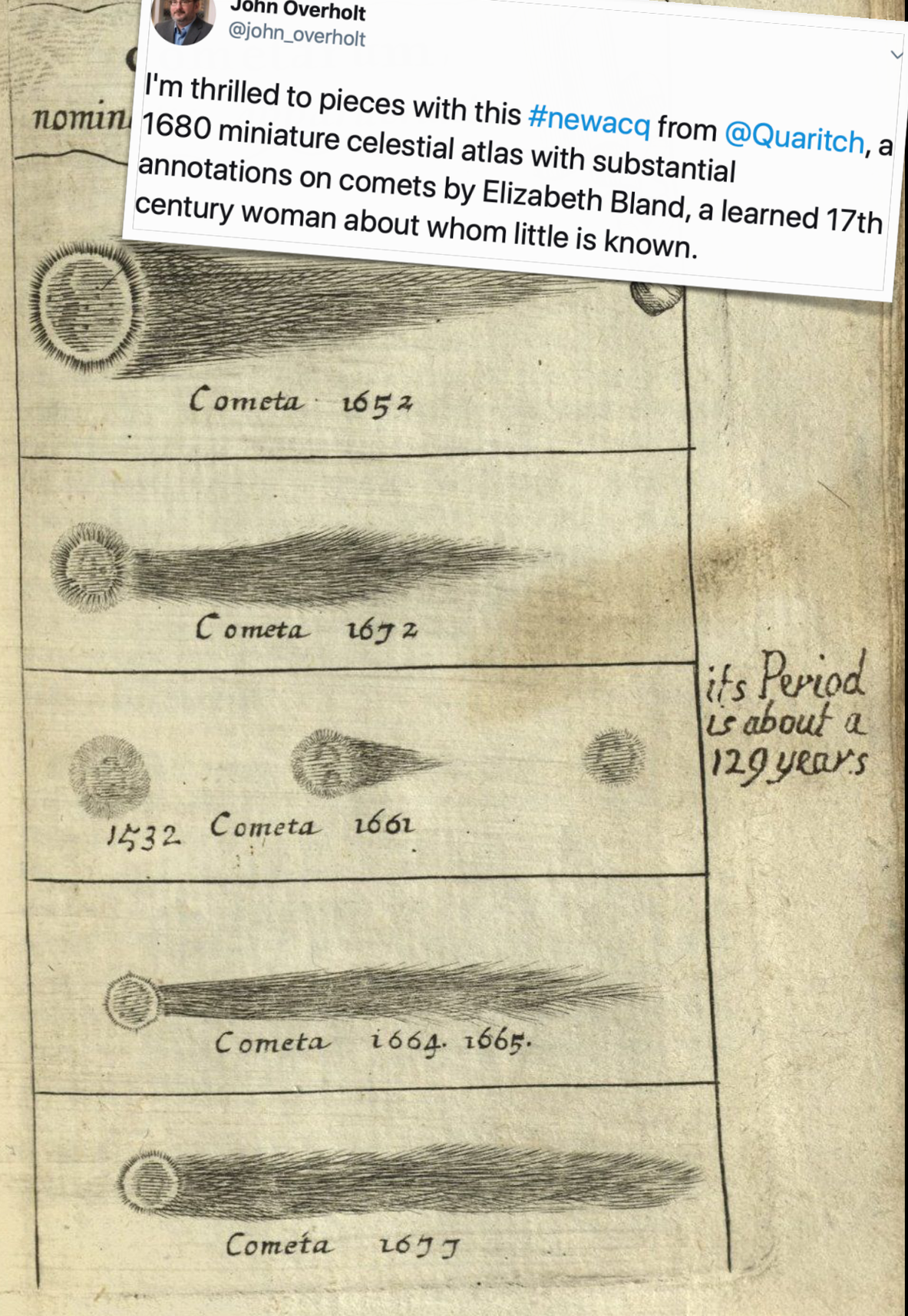
Two New Sciences
Galileo
1638

Principles of Philosophy
Descartes
1644

Principia
Isaac Newton
1687

Synopsis Astronomia Cometicae
Edmond Halley
1705

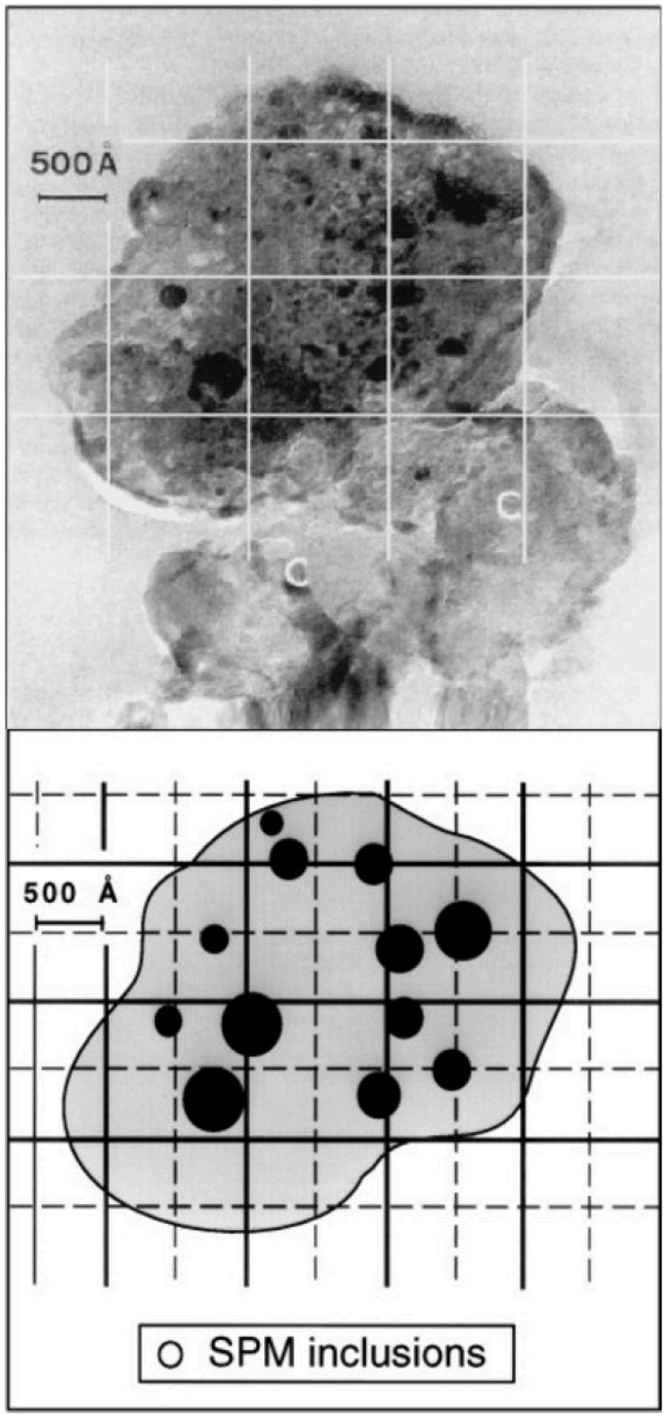
Comets in the Renaissance



Comets, Newton & Gravity(!)

(Simon Schaffer on the BBC, 2008)

Fig. 1. from A Point in Favor of the Superparamagnetic Grain Hypothesis
Goodman &
Whittet 1995 ApJL 455 L181 doi:10.1086/309840
http://dx.doi.org/10.1086/309840



Comets Today

we *navigate*
to them!

ROSETTA

12 years through space

Today: we use Newton's Laws to land on comets

Prediction: Week 11

SPACE!

From Fear to Landings: Comets

"Stardust"

Dynamics

The 3-body problem

n-body simulation

Illustris (+more physics)

Astronomy Simulation with **SPACE FUTURES** *experts from the CfA: Breakouts*

Avi Loeb

Jill Tarter

Predictions with the Drake equation (groups)

CONTACT(?)

The “3-Body” Problem

which Newton’s Law of gravity alone cannot exactly solve

Note: good overview at: en.wikipedia.org/wiki/Three-body_problem

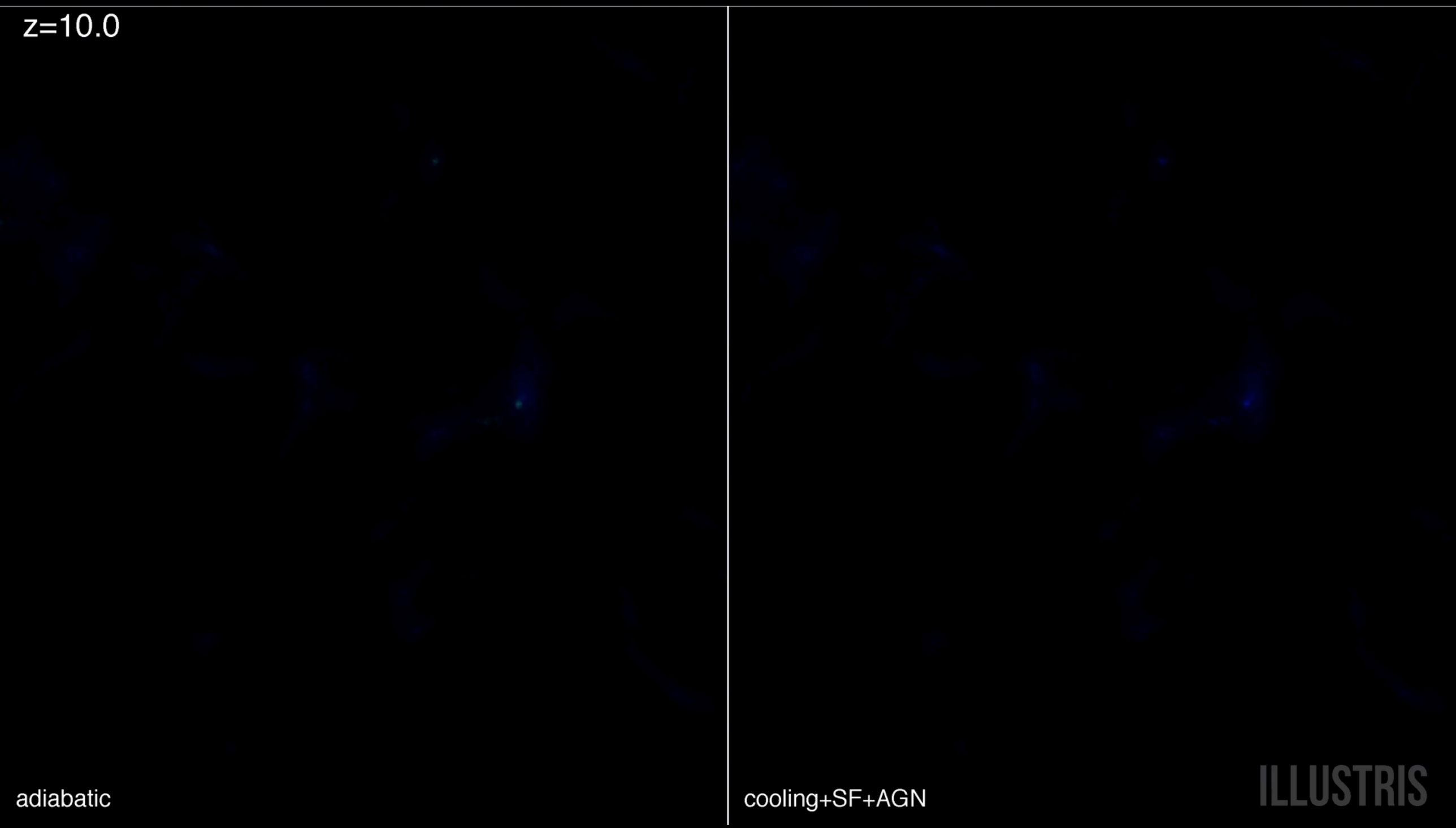
The “n-Body” Problem

The “n-Body” Problem

Simulation-Observation Comparison

Collisions sim vs. ops https://www.youtube.com/watch?v=C0XNyTp5brM

Illustris (+more physics)



Time evolution of a 10Mpc (comoving) over-dense region within Illustris. While the right side shows a full-physics simulation that includes gas cooling, as well as stellar and black hole formation and feedback, the left side shows a simple simulation of the same region, which includes only gravity and hydrodynamics.

Prediction: Week 11

SPACE!

From Fear to Landings: Comets

"Stardust"

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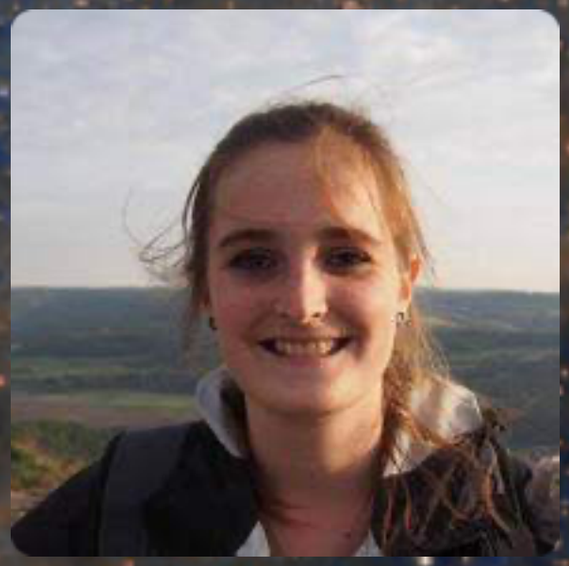
SPACE FUTURES

Making Stars & Galaxies



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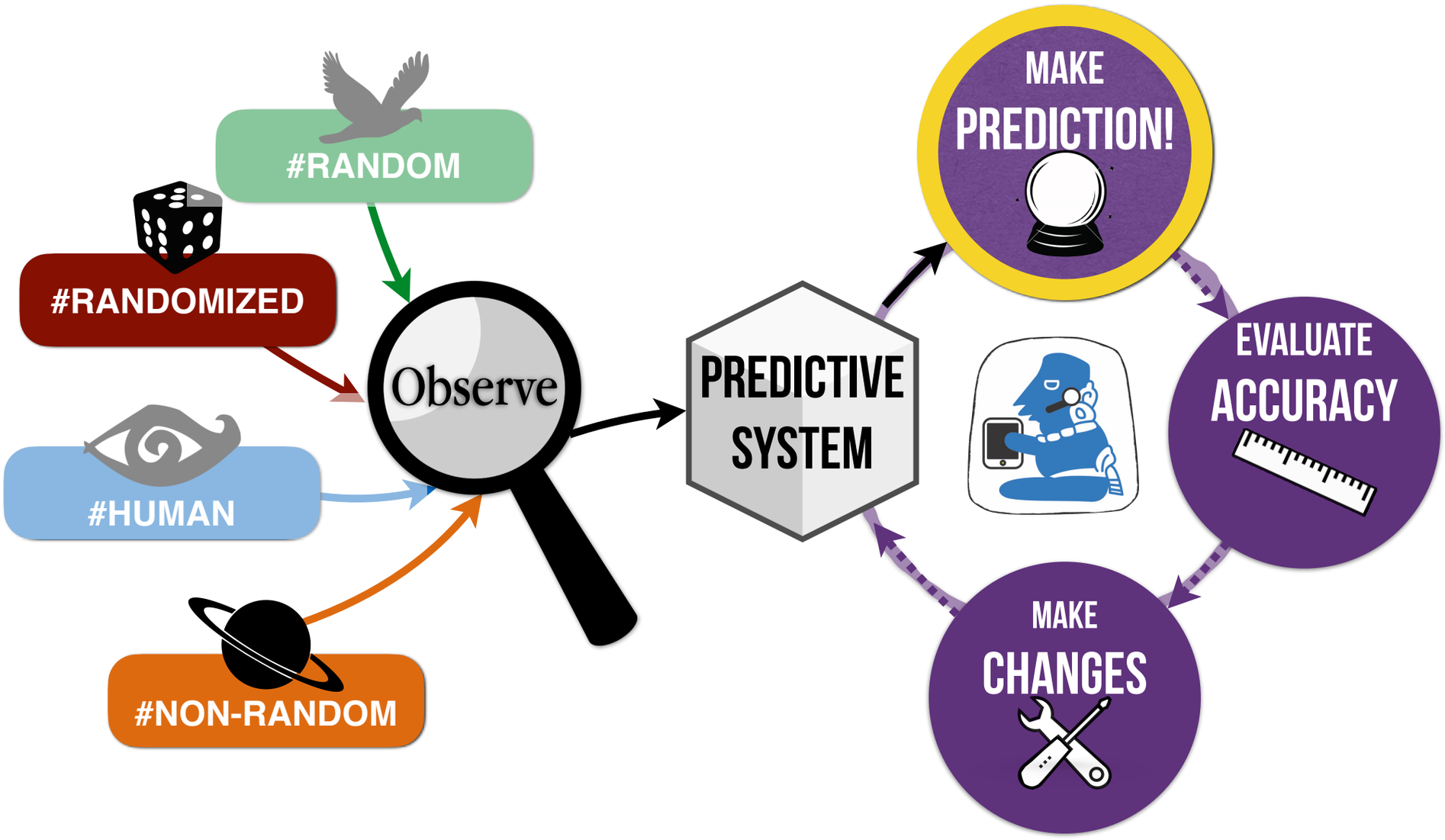
SPACE FUTURES

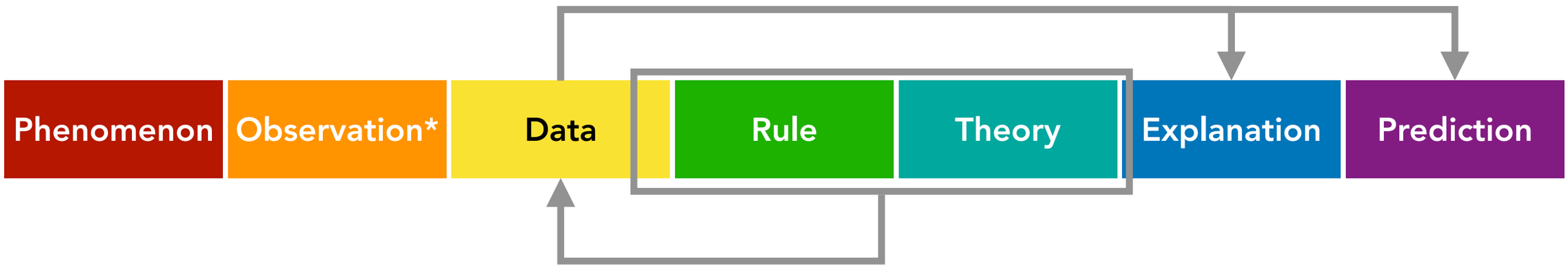
& the PredictionX Framework



https://openclipart.org/

SPACE FUTURES

& The Padua Rainbow



Some “**Data**” are used to provide “initial conditions,”

then, as **Rules** and **Theories** are applied,

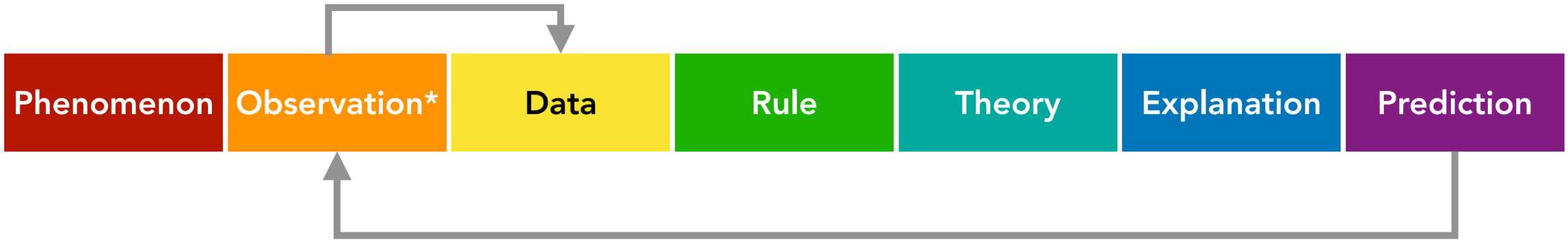
more “**Data**” are generated as simulation output,

and used to offer **Explanations** and/or **Predictions**.

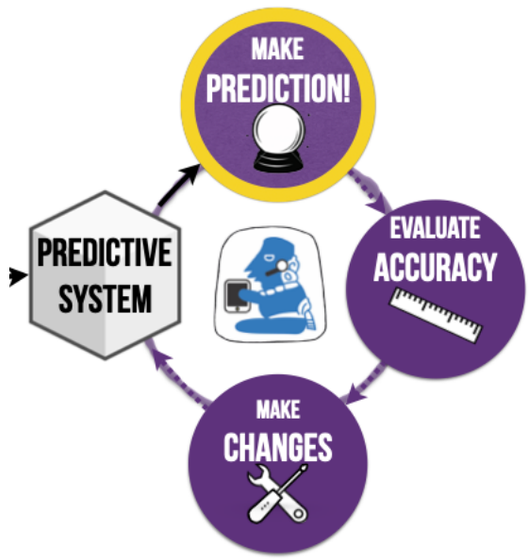
or, Experiment

SPACE FUTURES

& Synthetic Observations



Synthetic "Observations" are created by simulating particular observing techniques, generating synthetic "Data"



Which, after statistical comparison with real Data, facilitate improvement, as in the framework.

or, Experiment

Astronomy Simulation with **SPACE FUTURES** *experts from the CfA: Breakouts*

tinyurl.com/GenEd1112-SpaceDiscussion

Prediction: Week 11

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"Stardust"

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Avi Loeb

Jill Tarter

Predictions with the Drake equation (groups)

CONTACT(?)

Avi Loeb

Key takeaway for AG: Loeb's strong opinions about AI

If studies don't lead to deep understanding, we can't build on them (so they're not worth doing…for him?)

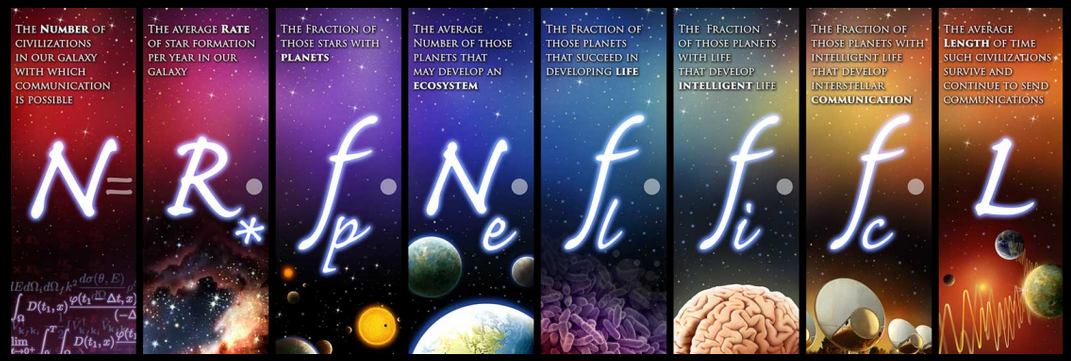
Jill Tarter

Key takeaway for AG: discussion of uncertainty caused by what's "undiscovered," unknown unknowns, etc.

If we didn't even imagine planetary systems unlike our Solar System, how can we imagine all the possible forms of alien life?

Predictions with the Drake equation (discussions if time)

The Drake Equation



Jodie Foster & Matthew McCounaghey in the movie CONTACT, copyright Warner Brothers 1997 (reproduced for educational use only) Disclaimer: Jill Tarter does not like mis-use of the Drake equation, which includes this scene.

The Drake Equation

The Drake Equation

Are We Alone in the Universe?

Calculate the Chance of Intelligent Alien Life with the Drake Equation

In 1961, Astronomer Frank Drake came up with an equation to estimate how many detectable extraterrestrial civilizations might exist in our galaxy. Each variable is a crucial factor for the development of alien life.

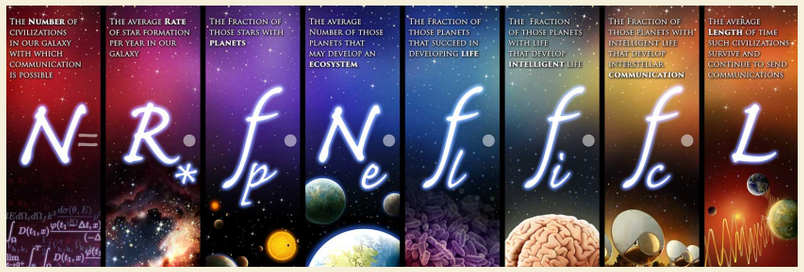
today's optimistic | lowest possible | original drake values | today's skeptical

No. of new stars born per year — f_p — **Average no. of habitable planets per solar system** — f_l — **% chance that life develops intelligence** — f_c — n_r

R^*	f_p	n_e	f_l	f_i	f_c	L	n_r
7	90	0.3	10	1	1	10,000,000	3
No. of new stars born per year	% of stars with planets	Average no. of habitable planets per solar system	% chance a habitable planet develops life	% chance that life develops intelligence	% chance life can communicate across space	No. of times civilisation could re-develop	

Calculate

Optional addition allows for the chance of civilization to re-evolve after collapse. An intuitive addition if you consider the billion year lifespan of planets.



informationisbeautiful.net/visualizations/the-drake-equation/

Heading here…